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EFFECT OF POST WELD AGEING TREATMENT ON TENSILE PROPERTIES AND MICRO STRUCTURAL CHARACTERISTICS OF FRICTION WELDED AA6061/SiC/GRAPHITE HYBRID COMPOSITES

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ABSTRACT

In this investigation, post weld ageing treatment and its effect on tensile and micro structural characteristics of extruded, friction welded hybrid AA6061/SiC/Graphite composites are experimentally analysed. The tensile strength, yield strength, notch strength and elongation were evaluated. They were found to be inter-related with micro-structural and hardness characteristics. The tensile as well as micro structural characteristics of as-welded and post weld artificially aged joints are compared. It is found that the strength seems to be higher in the as-welded joints.

KEYWORDS: Hybrid Metal Matrix Composites, Friction Welding, Stircasting, Extrusion, Artificial Ageing & Post Weld Ageing

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Original Article

1. INTRODUCTION

Aluminium hybrid metal matrix composites possess improved strength to weight ratio, excellent wear as well as corrosion resistance properties. The aluminium hybrid composites are utilised in advanced engineering applications for their improved mechanical properties. Conventional metallic alloys get replaced with hybrid aluminium matrix composites in many applications. Their applications include aerospace, automobile, ship industries. Powder and liquid metallurgy methods have wide application in the production of hybrid aluminium matrix composites. Compared with unreinforced alloys, the double synthetic ceramic reinforced hybrid aluminium composites possess good mechanical and wear resistance properties [1].

Solid-state welding like friction welding proves to be an alternative for fusion welding process. It eliminates the defects related with melting, solidification that happens in a fusion welding process. The continuous drive friction welding produces good joints in comparison with fusion welding process [2]. The percentage elongation of the aluminium metal matrix hybrid composites was drastically reduced due to increase in reinforcement content. The decrease in the ductility was due to the formation of voids and nucleation in the matrix around reinforcement materials [3]. Instead of single reinforcement, the addition of hybrid reinforcement has increased the hardness. The hardness gets increased because of the increase in the reinforcement content of the composite [4]. A rise of tensile strength can be noticed due to increase of the weight fraction of reinforcement

particles. The weight percentage increase of SiC and Graphite both combined, decreases the density of the composite as the graphite is present [5]. The metal matrix composites hardness has a linear relationship with the volume fraction of reinforcements [6]. Ageing kinetics is influenced in the composites as the particle reinforcements are present in the material [7]. If the reinforcement quantity is more, it affects the extruded quality, results in non-uniform mechanical properties[8]. As the high temperature was experienced in friction welding process in the HAZ (heat affected zone), the dissolution of the strengthening precipitates takes place. The HAZ has a low hardness value compared with base metal [9]. Dislocation of higher concentration very near to the aluminium matrix- silicon carbide interface accelerates artificial aging in the composites [10]. High forge pressures up to 150MPa were used to produce highly efficient joints [11]. Addition of reinforcements increases the hardness value in cast condition. The unreinforced alloy has a lesser hardness compared to reinforced alloy [12]. The precipitate behaviour of aluminium alloy during the welding thermal cycles has a role in the mechanical properties of the alloy. The variations in thermal effect together and welding conditions were a main reason for variation in hardness. The strength gets maximized in the weld during the post weld solution treatment [13]. A good bonding occurrence was observed with Al alloy matrix and 10% of SiC together with mica reinforcements [14]. The effective modification in microstructure and improvement in tensile properties can be noticed in friction stir welding process after post weld heat treatment. An important precipitate in Al-Mg-Si alloy is Mg_2Si. Solution treatment and ageing has a greater role in their generation together with distribution[16]. Ageing behaviour of SiC/Gr/6013Al composite has been analysed for both artificial ageing (T6) and natural ageing (T4). Peak hardness has been attained in a shorter time for SiC/Gr/6013Al composite [17]. In aluminium alloy composites with SiC as reinforcement, an increased SiC content resulted in the reduction of hardness during the over aged condition[18]. Grain refinement was observed owing to frictional heating in linear friction welding [19]. The strength of the extruded parent metal was found to be more compared with as-welded 6061/SiC/graphite hybrid composites using friction welding process.[20]. Ductile failure of aluminium matrix was observed without any notable change particle cracking during linear friction welding [21]. Since limited works were available this area, an investigation has been carried out to study the effect of post weld ageing treatment on tensile and micro structural characteristics of AA6061/SiC/graphite hybrid composites. A comparison has also been made on tensile, micro-structural and fracture appearances of as-welded and post weld artificially aged samples and the results were presented.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

AA6061 alloy was used as the matrix material. Magnesium and Silicon are major elements in 6061 alloy. SiC and graphite mixtures were the reinforcement materials. Silicon carbide (10 wt%) and graphite (5 wt%) were used in the experiments. AA6061 composition is shown in Table 1.

Table 1: Chemical Composition (wt%) AA6061

Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
0.9	0.62	0.33	0.28	0.17	0.06	0.02	0.02	Bal

2.2 Fabrication of Composites

Stir casting process was used as a fabrication method. Aluminium has been melted at 650℃ and after the removal of slag, the pre heated particles of SiC and Graphite were added and cast samples were fabricated. The cast samples are machined and subjected to hot extrusion process. The process of extrusion was carried out at a temperature range of 450℃-480℃.

After extrusion, specimens of length 60mm and diameter 12mm were machined and made ready.

(a) Stir Casting set up (b) Extrusion Process set up

Figure 1: Experimental set up for Fabrication of Composites.

2.3 Friction Welding

The specimens are then friction welded. In total, sixteen (16) joints were produced and the joints are shown in figure2.

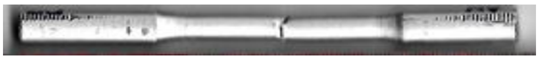
Figure 2: Friction Welded Samples.

2.4 Post Weld Heat Treatment

Eight samples were used for as-welded (AW) condition. They were not subjected to heat treatment. The remaining eight specimens were subjected to Artificial Ageing (AA). Artificial Ageing (AA) has been carried out at a temperature of 163°C and ageing time for 8 hours.

2.5 Tensile Property Testing

The friction welded samples, both as welded and aged specimens were subjected to mechanical characterization by conducting tension test as per ASTM B557 standard. Notched and Un notched specimens were subjected to tensile testing. Tension tests were also carried out on the extruded sample i.e., parent metal. Universal tensile testing machine capable of applying a maximum load of 100kN was used for tensile tests.



(a) AW condition -Before Testing (b)AW condition -After Testing

(c)AA condition -Before Testing

(d)AA condition -After Testing

Figure 3: Tensile Test Specimens

2.6 Micro Hardness Survey

Hardness variations were obtained using Vickers micro hardness tester. The load applied was 0.2 kg and the duration was 15 seconds. Hardness measurements were done on both sides of the joint.

2.7 Micro Structure Analysis

The optical micrographs of FDZ (Fully deformed Zone or Weld line), PDZ (Partially deformed zone or weld Zone), TMAZ (Thermo mechanically affected zone), BM(Base metal) for AW and AA joints were captured. The etchant used in the analysis was Keller's reagent.

2.8 SEM Analysis

FESEM (Field Emission Scanning Electron Microscopy) was carried out for analysing the pattern of distribution of particles in the composites. SEM and EDS were conducted on CARL Zeiss SUPRA-55, FESEM.

3. RESULTS AND DISCUSSIONS

3.1 Tensile Properties

Table 2 presents the tensile properties of the joints. Three specimens were taken for test in each condition and results were tabulated.

Table 2: Tensile Properties of AW and AA Joints

Joint type	Tensile Strength (MPa)	Yield Strength (MPa)	Percentage of Elongation	Notch Tensile strength (MPa)	NSR (notch strength ratio)	Joint Efficiency
Parent material	256	221	6.51	268	1.04	-
As-welded joint	167	147	4.52	173	1.03	65.23
Artificially Aged joint	148	122	6.48	156	1.05	57.7

As- welded (AW) joint has a tensile strength of 167 MPa. The parent material has a tensile strength of 256MPa. This shows that there was reduction in tensile strength up to 34.76% in the weld metal in comparison with parent metal. Post weld artificially aged sample possess a tensile strength of 148 MPa, which was 11.37% less than the tensile strength of as-welded sample. The joint efficiency in case of as-welded condition is 65.23%, while the post weld artificially aged treated specimens produced a joint efficiency of 57.7%. The percentage of elongation of the as-welded (AW) joints was found to be 4.52%. The elongation percentage of parent metal was 6.51%. The percentage of elongation achieved after post weld Artificial Ageing (AA) was 6.48%. The artificially aged friction welded joints produced tensile and yield strength values of 148 MPa and 122 MPa respectively, results in reduced joint efficiency up to 7.53% in comparison with AW joint. There was a 1.96% increase in elongation for AA joints compared with AW joint. The NSR evaluated was found to be more than unity in all joints. This reveals the fact that the joints are notch ductile.

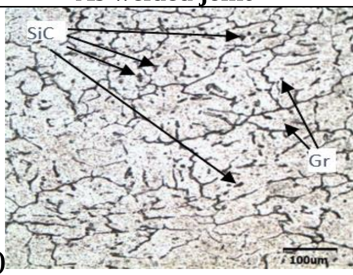
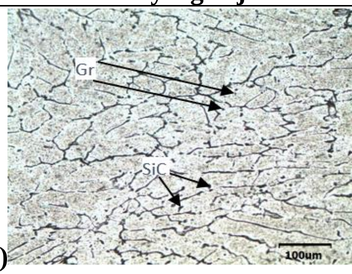
3.2 Micro Hardness

The hardness survey has been conducted using Vickers microhardness tester. The hardness survey was conducted at the

friction welded zone on the left and right side in the cross section. The hardness values show gradual descend as the distance moved away. It is observed that the weld zone of the AW joint shows high hardness value compared to AA joints. The FDZ (Fully Deformed Zone or Weld line) and PDZ (Partially Deformed Zone or weld Zone) region shows a reduction of hardness value in AA joints owing to the artificial ageing treatment. In contrast, the as-welded joints without age hardening show a high hardness value. Hence, the enhanced hardness of the as-welded samples is due to the rapid cooling taking place at the weld zone. The AW joints exhibits hardness, which is slightly higher compared to AA joints.

3.3. Micro-Structural Observation

The optical micrographs of Base Metal (BM), Thermo Mechanically Affected Zone (TMAZ) Partially Deformed Zone (PDZ), Fully Deformed Zone (FDZ) of AW, AA is shown in figure 5 a,b,c,d,e,f,g,h respectively. The BM region of AW joint (Figure5a) show distribution of composite particles. The primary aluminium grain shows grain size varying from 75µm to 100µm with eutectic particles precipitated at the grain boundaries. The BM region of AA joint (Figure5b) shows longer primary α aluminium grains precipitated with eutectic particle. The TMAZ region of AW joint (Figure5c) reveals directional orientation of grains. The micrograph shows fine acicular primary α aluminium in close proximity with eutectic particles at the grain boundaries. Figure 5d shows TMAZ of AA reveals larger grains of primary aluminium with no directional grain orientation. The grain size varies beyond 100 µm. It is evident that the grain growth could have taken place. Figure 5e and Figure 5 f, reveals the microstructure of PDZ region of AW and AA joints respectively. Figure 5g shows the FDZ region of the weldment where we can visualize the fine fragmented grains. They are re-oriented in perpendicular direction due to the frictional stress. Figure 5h shows the weld zone of the process with complete fusion of both sides of the metal matrix. The grains are finer with bonding of grains in the direction of weld.

<table>
<tr><th>Different Zones of Weld sample</th><th>As welded joint</th><th>Artificially Aged joint</th></tr>
<tr><td>BM</td><td>(a) 
</td><td>(b) 
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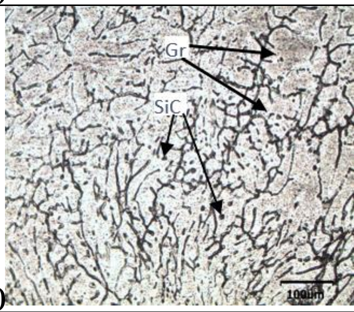
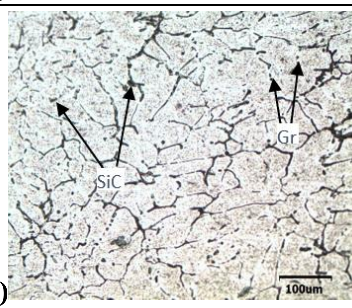
<tr><td>TMAZ</td><td>(c) 
</td><td>(d) 
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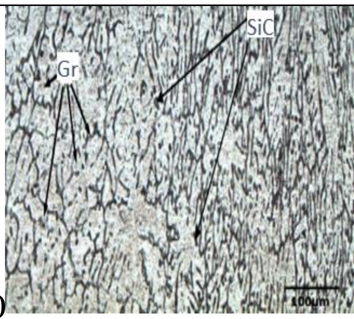
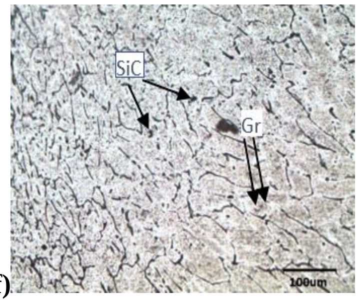
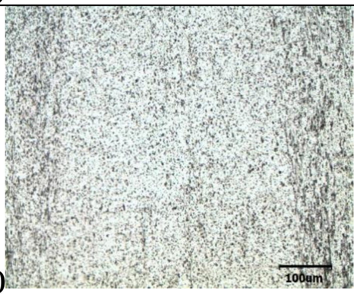
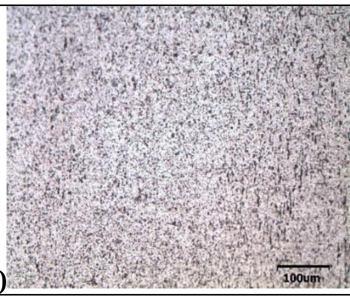
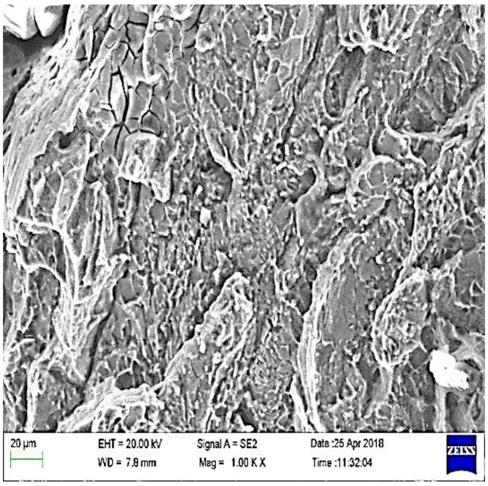
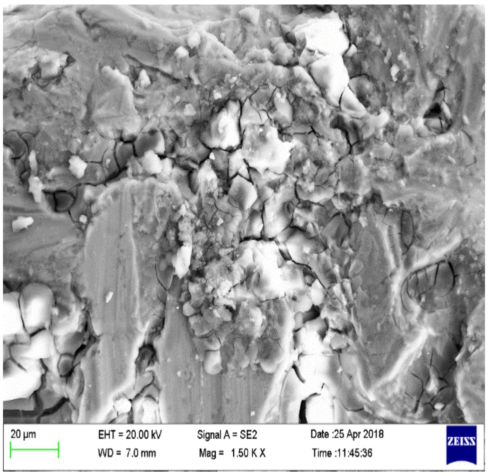
PDZ	 (e)	 (f)
FDZ	 (g)	 (h)

Figure 5: Optical Microscopy of Different Zones of AW and AA Joints.

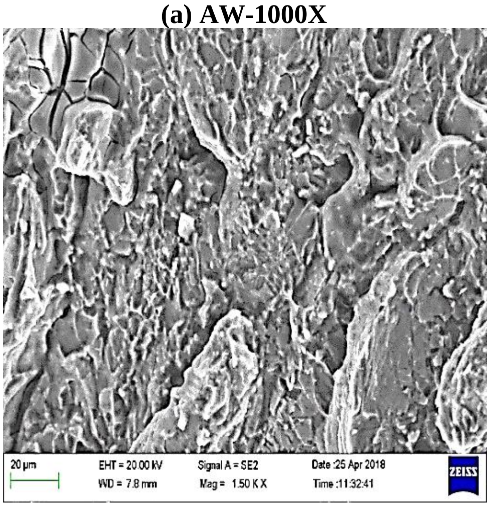
3.4 SEM-EDAX Analysis of Fracture Surfaces



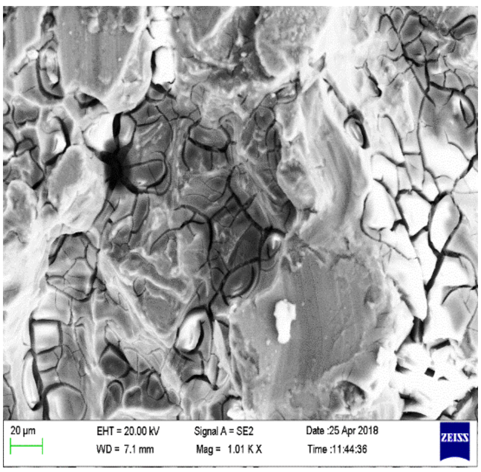
(a) AW-1000X



(b) AA-1000X



(c) AW-1500X

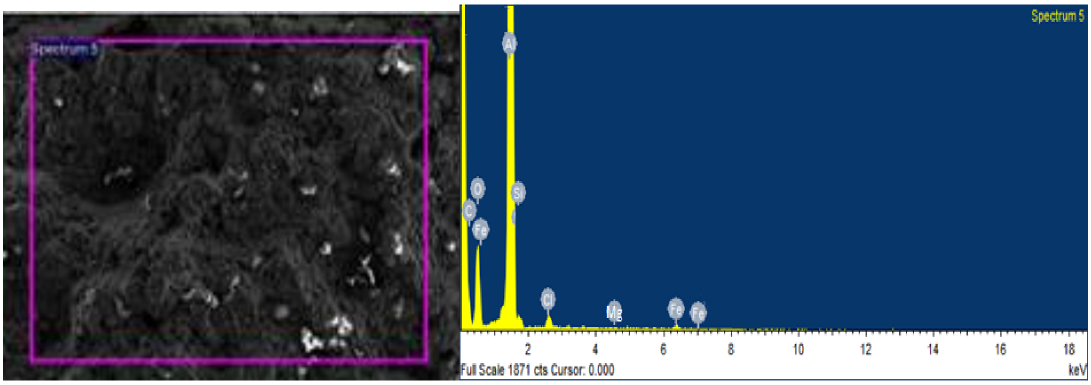


(d) AA-1500X

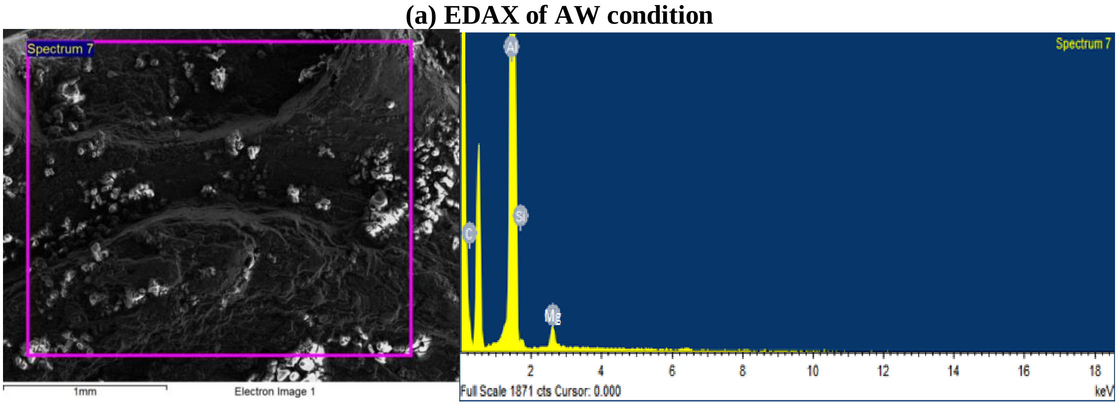
Figure 6: SEM Fractographs of Unnotched Tensile Specimen.

The figure6(a) shows the fractured surface morphology of friction welded surface at 1000X resolution. The SEM

micrograph shows the flow of grains of primary aluminium along the vertical direction of the weld surface. The fracture surface of AW joints show micro voids and dimples. This indicates the type of failure is ductile. The presence of reinforced particles was observed at the grain boundaries of primary aluminium grains. The figure 6(b) shows the fracture surface of the AA condition. It consists of deeper voids. The fracture surface of the AA joint contains coarser precipitates. During tensile loading, failure takes place at this location. The fig6(c) shows the same surface but at higher magnification of 1500X. The higher elongation and lower hardness were in agreement with the fractured grain morphology. The composite particles further resolved along the primary grains of the metal matrix. The Figure 6(d) shows the magnification of the field at 1500X resolved the grains and the fine grain boundaries of primary metal matrix. The effect of ageing could have facilitated the secondary eutectic particles in the primary solid solution. The fractured surface does not show any grain boundary cleavages.



(a) EDAX of AW condition



(b) EDAX of AA condition

Figure 7: EDAX results

Figure7a shows the fracture surface EDAX analysis of as- welded condition shows the presence of high carbon due to the presence of graphite and the silicon carbide. The field shows all the elements of primary metal matrix and the elements of composite particles. The higher oxygen content could be due to the oxidation of aluminium during friction welding process. The fracture surface EDAX analysis of artificially aged condition shows the presence of high carbon due to the presence of graphite and the silicon carbide (Figure7b). The field shows all the elements of primary metal matrix of AA 6061 and elements present in the composites. The fracture surface EDAX analysis shows the presence of carbon due to the presence of graphite and the silicon carbide. From the results, it was identified Mg_2Si was the predominant precipitate in all the joints.

4. CONCLUSIONS

In this investigation, the influence of post-weld Ageing treatment on tensile properties and micro structural characteristics

of friction welded AA6061 reinforced with silicon carbide and graphite was analysed in detail. The conclusions gained from the experimental results were as follows:

- The tensile strength of as- welded joints is 11.37 % more than that of the tensile strength of post weld AA joints. The joint efficiency is 7.53 % more in case of as welded samples compared with post weld artificially aged samples.
- The percentage of elongation is 1.96% more in case of post weld artificially aged joints compared with as- welded joints which indicate that post weld AA joints were more ductile than as- welded joints.
- The as- welded joints have higher hardness than the artificially aged joints.
- Examining the fracture surface, the artificially aged specimens shows large dimples which proves it possess lower strength. The ductility property is also more. The as-welded specimens show small dimples which proves it possess higher strength.

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